REPORT: Design performance and guidance for ESA-listed species' surveys in American Samoa.

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Summary

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Project Title:	Linking spatial patterns of *Isopora* with environmental drivers to improve assessment of ESA-listed corals in American Samoa
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The following Report, entitled "Design performance and guidance for ESA-listed species' surveys in American Samoa" is submitted as a deliverable from Project 31063: Linking spatial patterns of *Isopora* with environmental drivers to improve assessment of ESA-listed corals in American Samoa.

1.0 Introduction

In 2014, 15 Indo-Pacific coral species were listed as threatened under the Endangered Species Act (ESA) (79 FR 53851; September 10, 2014). The widespread geographic ranges reported for the majority of these species extend well beyond U.S. waters. Although a recovery plan has not been finalized, conservation and recovery of these Indo-Pacific, ESA-listed, coral species will include an ecosystem approach to encompass the variation in geographic distribution, habitats, and life history among species. Proxy species may be used to provide insight into recovery efforts where species-specific information is unknown or limited. This project was developed based on an overarching need to assess ESA-listed coral status in U.S. Pacific waters as well as to inform future survey efforts required to improve evaluation and demographic information of these threatened species. This report evaluated the statistical performance of surveys conducted by the Ecosystem Science Division (ESD) of the Pacific Island Fisheries Science Center (PIFSC) in American Samoa during 2015 as part of the National Coral Reef Monitoring Program (NCRMP).

1.1 Background and Report Goals

The overall project focused on *Isopora crateriformis,* which is the most abundant of the six confirmed ESA-listed coral species in American Samoa. Three species of *Isopora* have been reported in American Samoa - *I. crateriformis, I. cuneata,* and *I. palifera* but only I. crateriformis has been listed as threatened (Veron and Stafford-Smith 2000). Ideally, the suite of project analyses would have been conducted on species-level abundance data for *I. craterformis*. However, due to the similarity of encrusting morphologies between *I. crateriformis* and *I. cuneata*, it was not identified to the species-level across all surveys. After the completion of 2015 surveys in American Samoa, local taxonomy experts indicated that *I. cuneata* had not been found in the region. As a result, all components of this project used estimates of *Isopora* abundance at the genus level where colonies with the growth morphology associated only with *I. palifera* were excluded. These estimates to provide the best possible information about *I. crateriformis* (referred to as *I. crateriformis* proxy throughout the remainder of the report). Additionally, several reference coral species, at different levels of abundance and frequency of occurrence in American Samoa, were used to provide a range of survey effort required to achieve similar levels of precision in abundance across species as a proxy for other ESA-listed coral species confirmed within the region. The remaining five ESA-listed coral species confirmed in American Samoa are *Acropora globiceps, Acropora jacquelineae, Acropora retusa, Acropora speciosa*, and *Euphyllia paradivisa.*

The goal of this report is to evaluate the statistical performance of existing survey data to increase effectiveness of future surveys to assess ESA-listed coral populations in American Samoa as part of the recovery effort. The objectives include: 1) demonstrating the scales of survey effort required for selected coral species that represent a range of abundance and frequency of occurrence; 2) evaluating the survey design efficacy and expected performance of future surveys.

2.0 Methods

A total of 188 sites were surveyed within the American Samoan archipelago from February 15 to March 30, 2015 (Figure 2.1). Sanctuary (shown as marine protected areas, MPA) and non-sanctuary (open) areas are listed in Appendix Table A1. Around Tutuila Island, two sanctuary areas, Fagatele Bay and Aunu'u B, were ranked as the highest priority to be surveyed, however, we were able to minimally sample two additional sanctuary areas (Fagalua Bay and Aunu'u A) as well. Estimates for all four sanctuary areas around Tutuila are reported as even minimal sampling will provide quantitative information for future surveys.

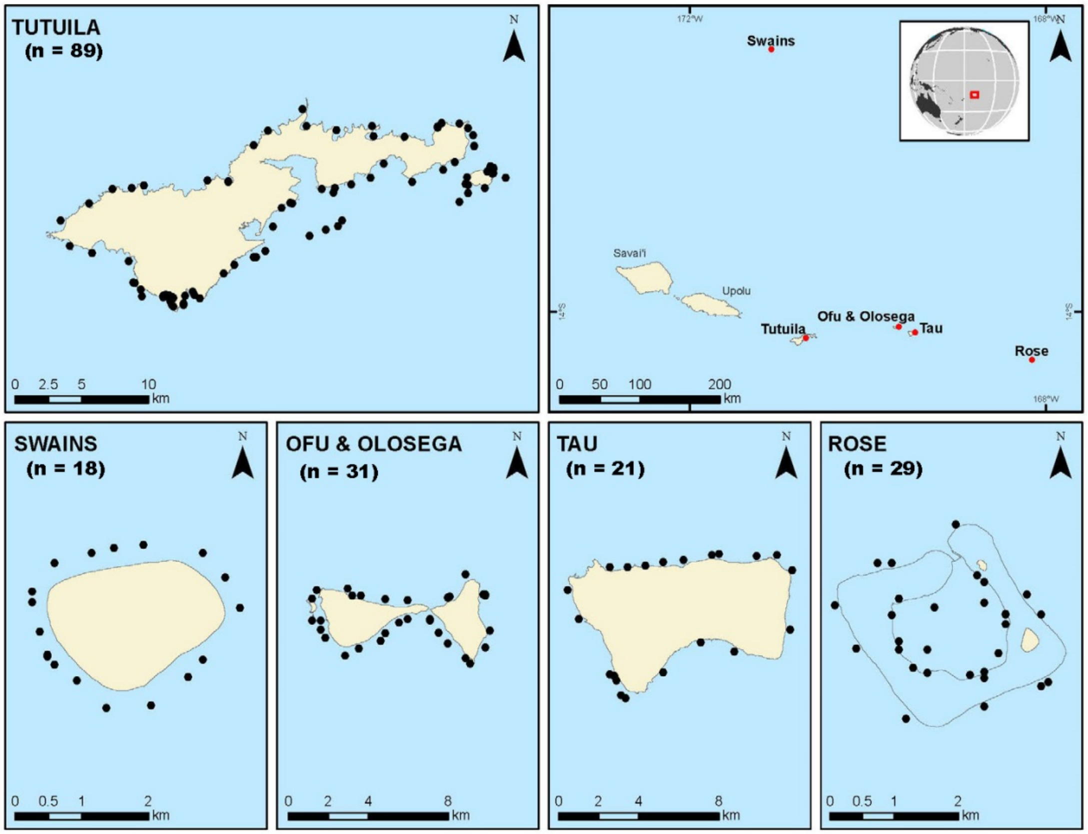

Figure 2.1. Site locations for the American Samoa survey during 2015.

2.1 Sampling survey design: Implemented survey

A two-stage stratified random sampling design was employed to survey the domain which encompassed hard bottom reef habitats from 0 to 30 meters around the islands of American Sāmoa. The stratification scheme incorporated island sectors (Tutuila only), three reef zones (fore reef, back reef, and lagoon), and three depth categories (shallow (0–6 m), mid (>6–18 m) and deep (>18–30 m)) where present (Appendix Table A1). In addition, selected marine protected areas (sanctuary areas) were included into the stratification scheme for Ta'u and Tutuila Islands (Appendix Table A1).

A geographic information system (GIS) and digital spatial databases of benthic habitats (NOAA National Centers for Coastal Ocean Science NCCOS), reef zones (NCCOS) bathymetry (ESD bathymetry data, http://www.soest.hawaii.edu/pibhmc/cms/data-by-location/american-samoa/), and marine reserve boundaries (NOAA) were used to facilitate spatial delineation of the sampling survey domain, strata, and sample units. A grid of 50m by 50m cells (2500m^2)was superimposed onto the survey domain. A two-stage sampling scheme following Cochran (1977) was employed to control for spatial variation in population parameters at scales smaller than the grid cell minimum mapping unit (2,500 m^2). Grid cells containing hard-bottom reef habitats were designated as primary sample units (referred to as sites throughout the remainder of the report), while the second-stage sample unit was defined as a diver visual belt transect of fixed area (10 m^2 or less; Smith et al. 2001). The specific details of two-stage stratified random sampling design implementation for coral reefs are described by Smith et al. (2011).

Allocation of sampling effort was proportional to total strata area. Site locations (geographic coordinates) were randomly selected within each stratum. Estimates for strata were generated from site means and were weighted by strata area. Island-scale and population domain estimates (means and totals) were calculated using weighted strata means.

2.2 Post-stratification design: habitat structure

The benthic maps used in the implemented survey design allowed for only the most basic stratification scheme that incorporates island sectors (Tutuila only) or island, reef zone (fore reef, back reef, lagoon) and depth category (0-6m, 6-18m, and 18-30m). However, the suite of analyses conducted for aspects of this project minimally required broad habitat structure sectors for Ofu and Olosega Islands, Rose Atoll, Swains and Tau Islands in addition to Tutuila Island. To accommodate this need, predominant wave energy (M. Jeannette Clark, ESD), existing tow diver survey data (ESD), ongoing benthic map revisions (ESD), as well as a geo-referenced 50 m by 50 m grid were used revise the benthic map to provide additional broad habitat structure sectors across all islands. The survey data collected during 2015 in American Samoa under the implemented design was post-stratified using island habitat sectors, reef zone and depth category (Appendix Table A2). Selected marine protected areas (sanctuary areas) were included into the stratification scheme for Ta'u and Tutuila as in the implemented survey design (Appendix Table A2). Strata, sector, island, and population (domain) estimates were generated as described above.

2.3 Field protocol

Benthic surveys at each site were conducted within two, 18-m belt transects. Adult coral colonies (≥ 5 cm) were surveyed within four (1.0 × 2.5 m) segments at 5 m increments on each transect (10 m^2 total per transect; Figure 2.2). Colonies were identified to genus, with the exception of a selected list of species that were consistently identifiable *in situ*. Adult coral colonies were classified by morphology type and measured at their maximum diameter (to the nearest cm). Each colony was assessed for partial mortality and condition. Partial colony mortality was quantified as the percent of dead tissue (classified as 'old dead' or 'recent dead'), and the cause of mortality was evaluated when possible. Conditions affecting each colony (i.e., disease and bleaching) were also noted, along with the extent (percent of colony affected) and severity (ranging from moderate to acute).

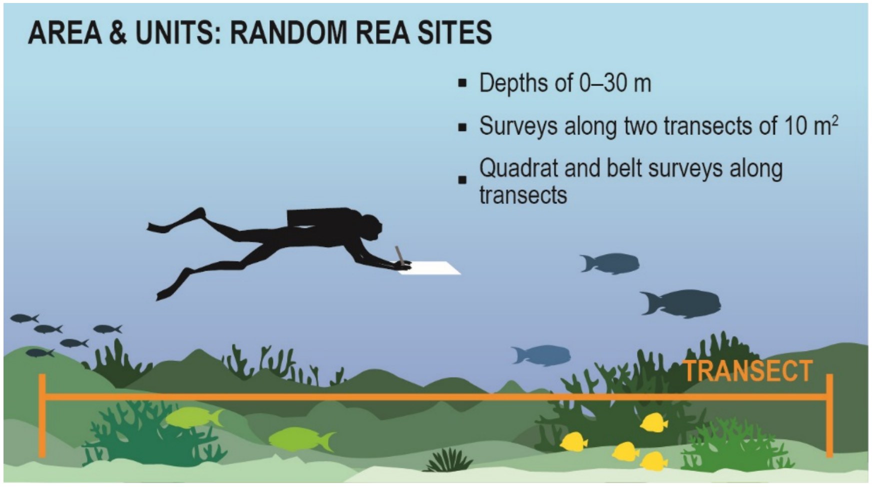

Figure 2.2. Schematic diagram of benthic Rapid Ecological Assessment (REA) method which shows one of two divers conducting a belt-transect survey along an 18 m transect line.

2.4 Performance evaluation

Statistical design performance was evaluated across a range of abundance and frequency of occurrence for six coral species (including the proxy for *I. crateriformis)* using precision of density estimates. Three performance measures were used to evaluate design efficacy of the 2015 survey data (both implemented and habitat structure designs) and the expected performance of a future survey (habitat structure design). These performance measures included: 1) the coefficient of variation (CV) of mean density – a measure of relative precision, 2) the optimum (minimum) number of transects required within a site to achieve an asymptotic estimate, and 3) the number of sites required to achieve a specified variance for a future survey (n*). The estimation of n* assumes a Neyman allocation scheme which incorporates both strata area and variance of strata densities.

3.0 Results and Conclusions

3.1 Coral species

A total of six species were selected for evaluation in three main categories to demonstrate the scale of precision and range needed for future survey effort: 1) abundant and high occurrence, 2) common to occasional abundance and moderate occurrence, and 3) rare abundance and low occurrence (Table 3.1). The first category included one species, *Montastraea curta*, which was one of the most abundant corals identified at the species level. The second category included three species (*I. crateriformis* proxy, *Platygyra daedalea*, and *Psammocora niestraszi*). All three have a frequency of occurrence between 20 and 30 % but density varied from 0.42 m^{-2} to 0.05 m^{-2} (Table 3.1). *I. crateriformis* proxy has highest density within the group and the density for *P. daedalea* and *P. nierstraszi* was much lower. The third category included *Coscinarea exesa* and *Turbinaria reniformis*). Estimates for density and frequency of occurrence were low for both species. These species can serve as a good proxy of a majority of the ESA-listed coral species in American Samoa as they are likely rare and have low occurrence.

Table 3.1. Weighted domain abundance estimates generated with the implemented survey design for selected adult coral species.

Species	Number of strata	Number of sites (PSU)	Density	SE_density	Freq. of occurrence (%)	SE_occur
Abundant and high occurrence						
Montastraea curta	42	188	0.654	0.076	72.99	3.17
Common-occassional and moderate occurrence						
Isopora crateriformis (proxy)	42	188	0.418	0.120	28.70	3.10
Platygyra daedalea	42	188	0.052	0.010	20.15	2.20
Psammocora nierstraszi	42	188	0.046	0.009	21.96	2.81
Rare and low occurrence						
Coscinarea exesa	42	188	0.006	0.003	2.88	1.41
Turbinaria reniformis	42	188	0.018	0.007	7.98	1.58

3.2 Future design performance

Stratification efficacy was evaluated by comparing implemented and habitat structure designs via post-stratification analysis (Table 3.2). The estimated CVs declined, indicating improved relative precision for all species with the incorporation of habitat structure design. The number of sites required to achieve a specific variance for future survey efforts (n*) decreased or was nominally different at 10 % and 15% target CV with the habitat structure design for both the *Abundant and high occurrence* coral species and the *Common-occasional and moderate occurrence* species. However, for the *Rare and low occurrence* species, n* increased substantially under the habitat structure design.

The habitat structure design was evaluated for the remaining two aspects of future design performance, because even with minimal sampling and post-stratification, improvements in precision were confirmed and the design provides the flexibility to conduct habitat use analysis which is important for assessment of ESA species.

The optimal sample size for transects (m*) was examined and the values for m* for each stratum were 2 or below for 100% of the strata for all species (Table 3.3). These results demonstrate that sampling two 10 m^2 belt transects was adequate for describing coral density within a 50 m by 50 m grid cell across all habitats and depths. In addition, reduction in variance was best achieved by sampling more sites rather than sampling more transects within a stratum.

The impact of allocation on the design performance is illustrated for all six species (Figures 3.1 – 3.3). The predicted sample size n* was computed over a range of CV values. A CV-n* curve represents the minimum bound of CV that could be achieved for a given stratification scheme assuming optimal allocation that includes both strata area and variance (Smith et al. 2011). Because reliable estimates of strata variance were not available prior to the implemented survey effort during 2015 in American Samoa, allocation of sites was based on strata areas only. In addition, these area allocated sites were post-stratified by the habitat structure design. For all species except the rare species, there was a substantial difference between the actual CV and the projected CV at n=188 which reflects the potential gain in precision that could be achieved in a future survey through optimal allocation. Optimal allocation uses strata area and variance of target species (Figure 3.1 and 3.2, Table 3.2). For the rare species, the actual CV is at or above the projected CV; however, the sample size to achieve a 15% CV was projected to be exceedingly large (Figure 3.3, Table 3.2).

These results demonstrated that the sampling effort needed to achieve a desired precision varied among species selected based on differences in their overall abundance and frequency of occurrence. For *I. crateriformis*, a common, moderate occurrence species, optimal allocation in future surveys would lower the sampling effort needed to achieve a target CV improving sampling efficiency and could substantially increase precision to provide a reliable assessment of this ESA-listed population. In contrast, the rare species, *C. exesa* and *T. reniformis*, demonstrated that the level of sampling necessary to achieve target CV are unrealistic.

Table 3.2. Post-stratification analysis results for six scleractinian coral species based on the American Samoa sampling survey (n=188, nm=269).

Design	Survey design	Number of strata	Density	CV (%)	n* (10%)	n* (15%)
Abundant and high occurrence						
(a) *M. curta*						
A	Implemented (actual survey)	42	0.654	11.65	105	47
B	Post-stratification: Habitat structure	55	0.629	10.11	87	39
Common-occasional and moderate occurrence						
(b) *I. crateriformis* (proxy)						
A	Implemented (actual survey)	42	0.418	28.64	206	93
B	Post-stratification: Habitat structure	55	0.306	26.62	208	95
(c) *P. daedalea*						
A	Implemented (actual survey)	42	0.052	18.98	354	159
B	Post-stratification: Habitat structure	55	0.046	17.55	306	138
(d) *P. nierstraszi*						
A	Implemented (actual survey)	42	0.046	19.88	343	155
B	Post-stratification: Habitat structure	55	0.045	19.27	334	151
Rare and low occurrence						
(e) *C. exesa*						
A	Implemented (actual survey)	42	0.006	51.50	2853	1423
B	Post-stratification: Habitat structure	55	0.004	47.46	4322	2250
(f) *T. reniformis*						
A	Implemented (actual survey)	42	0.018	39.45	1650	770
B	Post-stratification: Habitat structure	55	0.016	35.75	1862	874

Table 3.3. Evaluation of the optimal sample size for second-stage units (m^*_h) for the American Samoa habitat structure sampling survey. Estimates of m^*_h were made for each stratum where density was non-zero. Values are the relative frequency of strata.

Species	Number of strata	Number of strata evaluated	Relative frequency (%) of strata $m^*_h \leq 2$
Abundant and high occurrence			
M. curta	55	46	100%
Common-occasional and moderate occurrence			
I. crateriformis (proxy)	55	22	100%
P. daedalea	55	16	100%
P. nierstraszi	55	32	100%
Rare and low occurrence			
C. exesa	55	6	100%
T. reniformis	55	8	100%

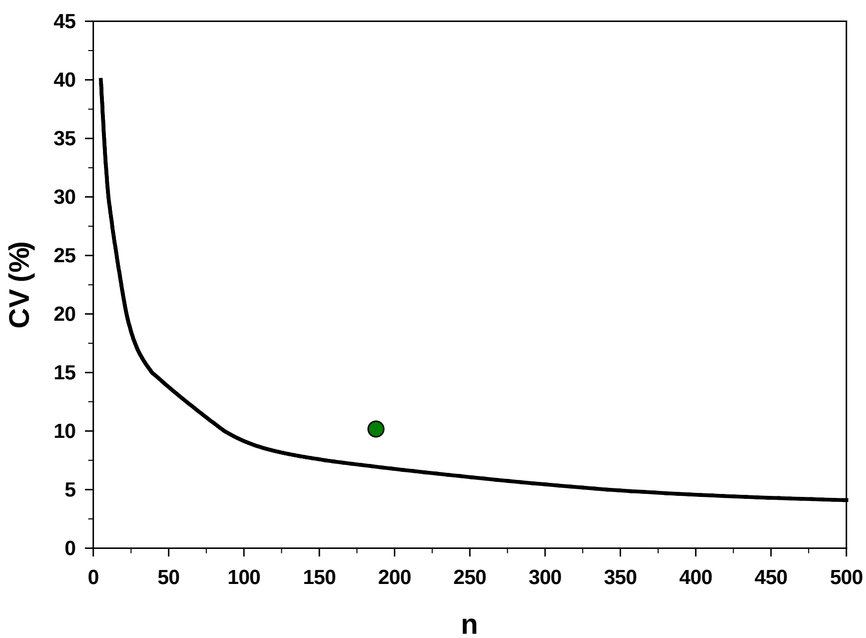

Figure 3.1. Relationship between coefficient of variation of mean density and predicted sample size n* estimated for the abundant coral species, *Montastraea curta*, based on the habitat structure stratified random sampling design. The point value of the actual coefficient of variation (CV) for M. curta and the sample size of 188 sites is denoted by the green circle

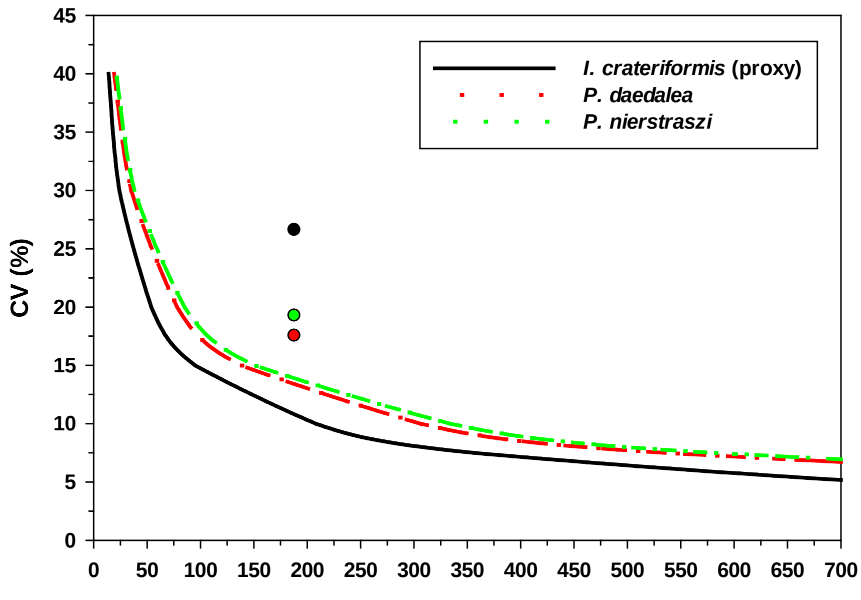

Figure 3.2. Relationship between coefficient of variation of mean density and predicted sample size n* estimated for three common to occasional species (*Isopora crateriformis* proxy, *Platygyra daedalea*, and *Psammocora nierstrazi*) based on the habitat structure stratified random sampling design. The point value of the actual coefficient of variation (CV) for all three species and the sample size of 188 sites is denoted by the colored circles.

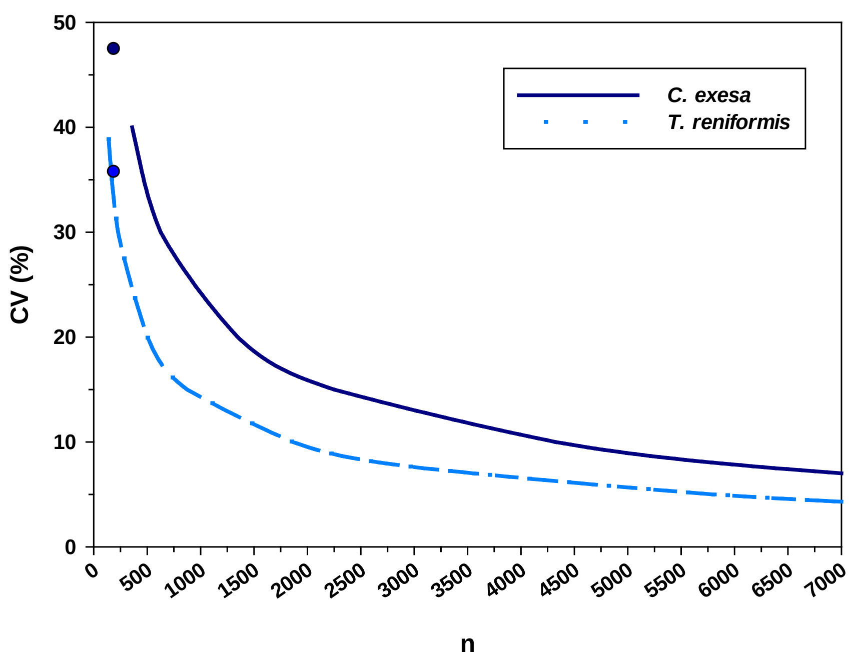

Figure 3.3. Relationship between coefficient of variation of mean density and predicted sample size n* estimated for two rare species (*Coscinarea exesa* and *Turbinaria reniformis*) based on the habitat

structure stratified random sampling design. The point value of the actual coefficient of variation (CV) for both species and the sample size of 188 sites is denoted by the colored circles

4.0 Summary

1. Selected species demonstrated performance at 3 levels – abundant (for contrast), common – occasional (to capture the more abundant listed coral species e.g. *I. crateriformis* proxy), and rare (proxy species for the rare ESA listed coral species).

2. The habitat structure design performed better than, or the same as, the implemented survey except for the rare species where both designs performed poorly.

3. For all species and across all strata, the optimal number of transects at site level was two 10 m^2 transects.

4. For all species except the rare species, the actual CV was larger than the CV vs n* curve which demonstrated that marked improvement that can be achieved through Neyman allocation.

5. The actual CV for rare species was at the steepest slope of the CV vs. n* curve and the sample size required to achieve even a 20% CV are unrealistic for most survey efforts. The cost of the survey may outweigh the benefit.

6. The habitat structure design had minimal sampling effort across a significant portion of the sampling framework yet density estimates for all species showed an increase in precision. This demonstrated that effective stratification by incorporating additional habitat covariates was also important for design performance. This can be achieved through improvement in benthic maps.

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Appendix Table A1. Islands, sectors, protection types, reef zones and depth categories that defined statistical strata in the American Samoa implemented sampling survey. The total possible primary units (N_h; 50 m x50 m grid cells) and sampled sites or primary units (n) are listed.

Island/Sector	Management level	Reef zone	depth category	stratum (h)	n	N_h
Ofu and Olosega	Open	Fore reef	Deep	1	9	1215
			Mid-depth	2	14	1476
			Shallow	3	8	483
Rose	MPA - NWR	Back reef	all depths	4	9	685
	MPA - Sanctuary	Fore reef	Deep	5	2	66
			Mid-depth	6	6	341
			Shallow	7	3	74
	MPA - NWR	Lagoon	Deep	8	4	298
			Mid-depth	9	3	110
			Shallow	10	2	9
Swains	MPA and Open	Fore reef	Deep	11	4	49
			Mid-depth	12	6	229
			Shallow	13	8	843
Tau	MPA	Fore reef	Deep	14	2	97
			Mid-depth/Shallow	15	3	344
	Open	Fore reef	Deep	16	3	717
			Mid-depth	17	9	1980
			Shallow	18	4	478
Tutuila NE	MPA - Aunu'u A	Fore reef	Deep	19	2	317
			Mid-depth	20	2	606
			Shallow	21	2	91
	MPA - Aunu'u B	Fore reef	Deep	22	4	811
			Mid-depth	23	4	163
			Shallow	24	2	1
	Open	Fore reef	Deep	25	5	1174
			Mid-depth	26	7	1094
			Shallow	27	5	1001
Tutuila NW	Open	Fore reef	Deep	28	3	1031
			Mid-depth	29	3	881
			Shallow	30	2	522
Tutuila SE	Open	Fore reef	Deep	31	5	1167
			Mid-depth	32	12	2638
			Shallow	33	5	1891
Tutuila SW	MPA - Fagalua Bay	Fore reef	Deep	34	2	31
			Mid-depth	35	2	111
			Shallow	36	2	27
	MPA - Fagatele Bay	Fore reef	Deep	37	4	18
			Mid-depth	38	4	81
			Shallow	39	5	38
	Open	Fore reef	Deep	40	2	1034
			Mid-depth	41	2	799
			Shallow	42	3	809

Appendix Table A2. Islands, sectors, protection types, reef zones and depth categories that defined statistical strata in the American Samoa habitat structure survey design. The total possible primary units (N_h; 50 m x50 m grid cells) and sampled sites or primary units (n) are listed.

Island/Sector	Management level	Reef zone	depth category	stratum (h)	n	N_h
Ofu and Olosega NW	Open	Fore reef	Shallow	1	4	379
			Mid-depth	2	6	708
			Deep	3	5	590
Ofu and Olosega SE	Open	Fore reef	Shallow	4	4	405
			Mid-depth	5	8	553
			Deep	6	4	510
Rose North	MPA	Fore reef	Shallow	7	2	10
			Mid-depth	8	4	227
			Deep	9	1	61
Rose South	MPA - Sanctuary	Fore reef	Shallow	10	1	14
			Mid-depth	11	2	100
			Deep	12	1	24
	MPA - NWR	Lagoon	Shallow	13	2	49
			Mid-depth	14	3	255
			Deep	15	4	618
		Back reef	Shallow	16	7	1543
			Mid-depth/Deep	17	2	62
Swains NW	MPA and Open	Fore reef	Shallow	18	6	87
			Mid-depth	19	3	134
			Deep	20	2	28
Swains SE	MPA and Open	Fore reef	Shallow	21	2	73
			Mid-depth	22	3	95
			Deep	23	2	21
Ta'u	Open	Fore reef	Shallow	24	4	578
Ta'u NW			Mid-depth	25	5	845
			Deep	26	1	485
Ta'u SE	Open	Fore reef	Mid-depth	27	4	901
			Deep	28	2	355
	MPA	Fore reef	Shallow	29	2	58
			Mid-depth	30	1	241
			Deep	31	2	104
TUT NE	MPA - Aunu'u A	Fore reef	Shallow	32	2	55
			Mid-depth	33	2	477
			Deep	34	2	448
	MPA - Aunu'u B	Fore reef	Shallow	35	2	9
			Mid-depth	36	4	113
			Deep	37	4	907
TUT SW	MPA - Fagalua Bay	Fore reef	Shallow	38	5	22
			Mid-depth	39	4	76
			Deep	40	4	32
	MPA - Fagatele Bay	Fore reef	Shallow	41	2	24
			Mid-depth	42	2	79
			Deep	43	2	44
TUT NE	Open	Fore reef	Shallow	44	5	600
			Mid-depth	45	7	1323
			Deep	46	5	1740
TUT NW	Open	Fore reef	Shallow	47	2	424
			Mid-depth	48	3	778
			Deep	49	3	1501
TUT SE	Open	Fore reef	Shallow	50	5	608
			Mid-depth	51	12	1908
			Deep	52	5	1659
TUT SW	Open	Fore reef	Shallow	53	3	484
			Mid-depth	54	2	699
			Deep	55	2	1220